Carnegie Mellon
Software Engineering Institute

Basic Concepts of Product Line Practice for the DoD

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February 2000

Product Line Systems Program

Technical Note
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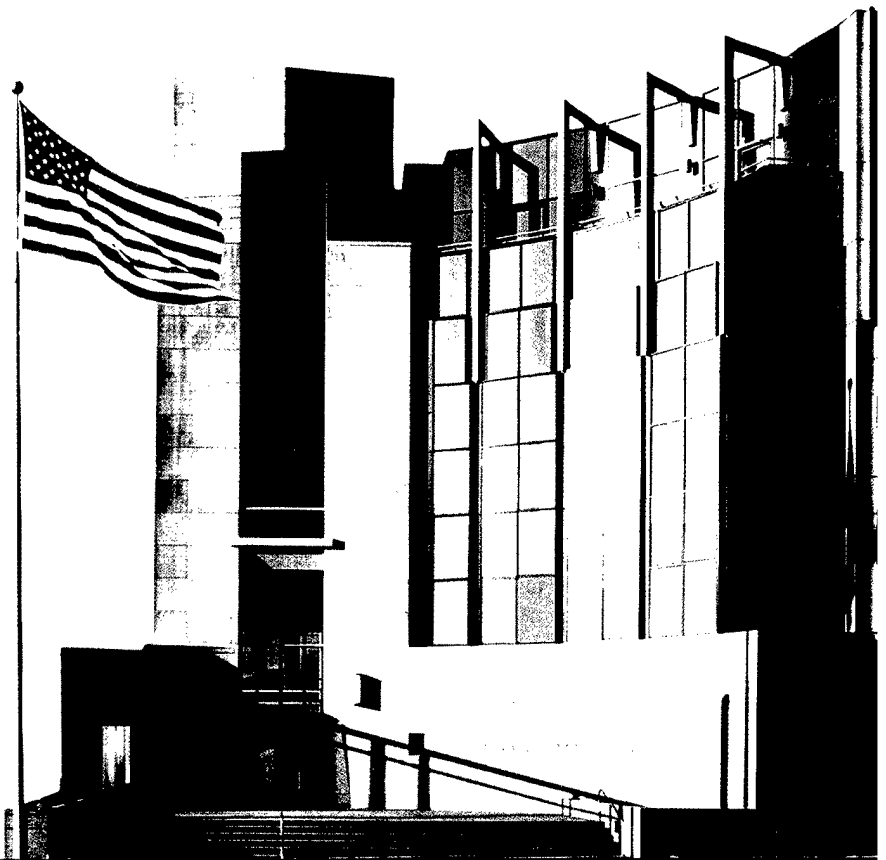*Brian Gallagher*
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About the Technical Note Series on Business and Acquisition Guidelines

The Product Line Systems Program is publishing a series of technical notes designed to condense knowledge about product line acquisition and business practices into a concise and usable form for the Department of Defense (DoD) acquisition manager and practitioner. Each technical note will focus on one aspect of adopting software product line practice in the Department of Defense. Our objective is to provide practical guidance to early adopters on ways to integrate sound product line practices into their acquisitions. By investigating best commercial and government practices, the SEI is covering new ground to overcome challenges and increase the understanding, maturation, and transition of software product lines.

Together, the technical notes will lay down a conceptual foundation for DoD product line business and acquisition practices that is consistent with the SEI's product line practice framework [Clements 99].

While we intend each technical note to be distributed and read as a standalone document, this particular technical note provides background information that may be helpful in understanding the other notes in this series. Additionally, a brief overview of software product lines is provided in *A Framework for Software Product Line Practice, Version 2.0* [Clements 99]. Other information on product line practices, including the latest version of the SEI's Framework for Software Product Line Practice, is available on the SEI's Web page at http://www.sei.cmu.edu/activities/plp/plp_init.html.

Abstract

Industrial experience demonstrates clearly that a product line approach for software-intensive systems can save money and result in faster time to field higher quality systems. Many within the Department of Defense (DoD) recognize the benefits of product lines, but also recognize that there are significant challenges to adopting this approach. Many of these challenges stem from the fact that the DoD is in the business of acquiring systems rather than developing them.

The Product Line Systems Program is publishing a series of technical notes designed to condense knowledge about product line acquisition practices into a concise and usable form for the DoD acquisition manager and practitioner.

This technical note provides background information about product lines to serve as a foundation for other technical notes in this series. Key terms, concepts, and benefits of a product line approach are given. Additionally, concepts of product line acquisition in a DoD context are discussed.

1 Introduction

A product line approach to developing and deploying software-intensive systems offers great promise for delivering higher quality systems in a shorter time and at reduced cost. Documented benefits include order of magnitude decreases in software development cost and system integration time. [Bass 97, Bass 98, Bass 99]. While many commercial firms and Department of Defense (DoD) contractors are already engaged in product line practices, most DoD organizations are still in the early stages of determining how product lines can best be applied in the DoD acquisition environment.

While these DoD organizations have recognized the benefits of product lines and promote the concepts upon which they are built (e.g., architecture-centric development, open systems, and systematic software reuse), they have also recognized that there are several technical and non-technical challenges to fully embracing product lines within the DoD acquisition environment. Many of the non-technical challenges translate directly into acquisition-related issues stemming from the DoD acquisition environment itself.

The DoD environment is based, in part, upon the requirements and guidance specified in high-level policies and regulations. The policies and regulations do not in themselves present a barrier to embracing a product line approach. However, often the local, cultural interpretations of these doctrines do present barriers. Within the current DoD acquisition environment, it is not unusual for major systems to require 7 to 10 years to progress from conceptualization, through research and development, design, integration, test, to deployment. Most of these systems are structured to work in isolation—as stand alone efforts. With such stand-alone development efforts, the DoD typically must re-learn many of the same lessons in each development. Moreover, money is being expended in many cases to build systems having common elements that have been developed by other programs. Currently, the DoD is not taking full advantage of opportunities across projects to leverage already developed assets. Such leveraging can improve reliability and affords common operations and training, not to mention reduction of required funding and faster deployment times. Another challenge is the trend in staffing and budgeting. Downsizing of the DoD workforce and shrinking budgets have placed more and more emphasis on the acquisition aspects of such software-intensive systems, rather than on "in house" development. This shift in emphasis also applies to the acquisition of services for sustaining these systems. This movement toward a leaner workforce has heightened the need for a skilled

workforce, especially for the acquisition management of the software in these software-intensive systems.

While these challenges can be formidable, they are not insurmountable. What is needed are innovative approaches to system acquisitions that take advantage of the guiding principles of acquisition reform, leverage assets across projects, compensate for workforce reductions and budgetary constraints, and enable deployment of high quality systems faster and cheaper, while still satisfying the users. Product line practice offers an approach that can help satisfy these DoD needs, and there are several examples of successful use of product lines within the DoD [Bergey 98[1]].

To examine the "fit" of a product line approach within the DoD acquisition environment, we need to understand the concept of a software product line and considerations involved in commissioning a contractor(s) to develop and evolve elements of a product line. This technical note, along with the software product line practice framework [Clements 99], provide background information about product lines to serve as a foundation for other technical notes in this series. Key terms, concepts, and benefits of a product line approach are given, followed by a discussion of product line acquisition concepts in a DoD context.

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[1] See also Bergey, John, et al. *Second DoD Product Line Practice Workshop Report* (CMU/SEI-2000-TR-002). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University. Expected publication date, March 2000.

2 Software Product Line Basics

2.1 Key Concepts

The field of software product lines is new enough to offer different definitions for similar concepts. The SEI has derived a definition from the hard goods industry that brings together the key intent of these sometimes-competing definitions. We define a product line as

> *a group of products sharing a common, managed set of features that satisfy specific needs of a selected market or mission* [Clements 99]

For example, a lawnmower company may offer a number of riding mowers that share a similar market strategy and a common set of features, but vary in some distinct ways. These products would be grouped together and referred to as a product line of riding mowers. They would be marketed as a product line. Customers would come to recognize the product line by name and select from the products in the product line according to the features that suit their individual needs. From a manufacturing standpoint, all of the mowers in the product line would be built to take economic advantage of the features they have in common. They would share a common overall design, common parts, common tooling, common manufacturing processes, common quality control procedures, etc.—all assets in the mower product line.

A software product line is no different in definition, concept, or motivation. It simply makes sense to treat groups of software products that have a common, managed set of features as a product line. The best way to build a software product line to take economic advantage of the features they have in common is for them to share a common architecture that is used to structure components from which the products are built. The architecture and components are central to the set of core assets (sometimes referred to as the *asset base* or *platform*) used to construct and evolve the products in the software product line. The individual products in the product line are built from these core assets according to a pre-defined production plan, sometimes called a reuse guide. Software product lines provide systematic reuse of the core assets.

Since software reuse is not a new concept, how does product line practice differ from earlier, less successful reuse efforts? Early efforts focused on small-grained reuse of software code. The cost of creation and use of these small-grained assets often outweighed the modest gains. Over the years, reuse technology has evolved

to focus on progressively larger-grained assets Today, the state of the art is to reuse strategic, large-grained reusable assets such as a software architectures, architectural frameworks, processes, test cases, components, and production plans to guide the creation of products. Using this more system-focused approach, reuse can result in remarkable benefits. Some examples of these gains are described in the next section.

2.2 Benefits of a Product Line Approach

A number of organizations have already gained order-of-magnitude improvements in efficiency, productivity, and quality through a product line approach. Often even more important than cost savings is the fact that product line practice enables an organization to more rapidly field products to satisfy operational needs. For the DoD, this factor is key, allowing for the rapid deployment of new technologies and capabilities to support the war fighter. As Robert Harrison, Naval Systems Warfare Center, succinctly stated, "The right answer delivered late is the wrong answer" [Bergey 98].

Specific quantified benefits of software product line practice have been reported in workshops and case studies conducted by the Software Engineering Institute [Brownsword 96, Bergey 98[2]]. For example, the Swedish naval defense contractor, CelsiusTech, reported a reversal in the hardware-to-software cost ratio, from 35:65 to 60:20, that now favors the software [Brownsword 96] as a result of their software product line approach for defense ship systems. Hewlett Packard has collected substantial metrics showing two to seven times cycle time improvements with product line practices. Motorola has shown a four times cycle time improvement with 80% reuse on their Flexworks pager product line Cummins Engine realized a decreased time for system build and integration from about one year to as little as three days in one case. Among other organizations that have shown efforts yielding equally dramatic product line results are: Thompson-CSF in air traffic control systems, Alltel in commercial bank systems, Ericsson, Nokia, Lucent, and AT&T in telecommunication systems, Buzzeo in college registration systems, Boeing in airflight software, and the National Reconnaissance Office in ground-based command and control systems for satellites.

The reported benefits are compelling, but what do you actually *do* when you engage in a product line approach? In the next section we describe the high-level, essential product line activities.

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[2] See also Bergey, John, et al. *Second DoD Product Line Practice Workshop Report* (CMU/SEI-2000-TR-002). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University. Expected publication date, March 2000.

2.3　Essential Activities of a Product Line Practice

At its essence, fielding a product line involves *core asset development or acquisition* and *product development or acquisition* using the core assets [Clements 99]. Formally, product line practice is defined as

> *the systematic use of software assets to modify, assemble, instantiate, or generate the multiple products that constitute a product line*

Multiple verbs appear in this definition because there are a variety of ways in which the core assets can actually be used to create products. The production plan would elaborate on which technique is to be used for a given product line.

The activities of core asset and product development/acquisition can occur in either order, or (most commonly) in concert with each other. Core asset development/acquisition has been traditionally referred to as domain engineering. Product development/acquisition from core assets is often called application engineering. The entire process is staffed, orchestrated, tracked, and coordinated by management. Figure 1 (Essential Activities of Product Lines) illustrates this triad of essential activities. The iteration symbol at the center represents the decision processes that coordinate the activities.
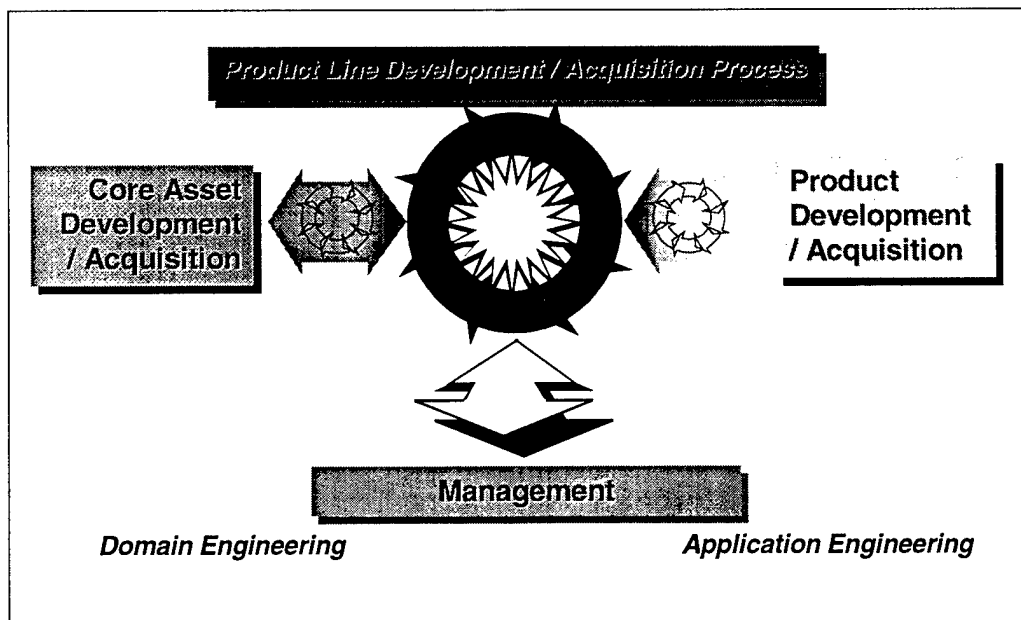
Figure 1: Essential Activities of Product Lines

The bi-directional arrows indicate not only that core assets are used to develop products, but that revisions to core assets or even new core assets might, and most often do, evolve out of product development. The diagram does not specify which part of the diagram is entered first. In some contexts, already-existing products are mined for generic assets that are then migrated into a product line. At other times,

the core assets may be developed or procured first in order to produce a set of products that is merely envisioned (i.e., planned) and does not yet exist.

There is a strong feedback loop between the *core assets* and *products*. Core assets are refreshed as new products are developed. The potential value of the core assets is realized through the number of products that are developed from them. As a result, the core assets are typically made sufficiently generic by considering potential new products on the horizon. Finally, both the core asset and the product development/acquisition are themselves iterative, as illustrated in Figure 1.

Software product lines are not a panacea, but can have colossal impact if properly used. Before embarking on a product line approach, it is important to understand the business goals and to develop a business case for choosing product line practices. It is also very important to carefully scope the product line. A product line that potentially includes too many systems may need to support an unwieldy amount of variation.

In this section, we have discussed the high-level product line activities in terms of both development and acquisition of core assets and products. More detail can be found in *A Framework for Software Product Line Practice* [Clements 99]. In the next section, we will concentrate more on the acquisition aspects of product line practice.

3 Product Line Acquisition

3.1 Terminology

For the DoD, the term acquisition can have several meanings depending upon the individuals involved or the programs involved. For consistency throughout this series of technical notes, we will rely on the definition from the Federal Acquisition Regulation (FAR), in which acquisition is defined as

the process of obtaining products and services through contract

Although acquisition and contracting are often used interchangeably, acquisition is really the *process* of obtaining through contract. A contract is a binding agreement between two or more parties that establishes the requirements for the products and services to be acquired. The *process* involves significantly more effort than just contracting, such as planning, requirements definition and management, solicitation, and evaluation [Ferguson 96].

Another important concept is that of an acquisition strategy. Again, this term can have several interpretations. For our purposes we define an acquisition strategy as

a plan of action for achieving a specific goal or result through contracting for products and services

Acquisition strategies from a product line perspective introduce a new paradigm into DoD traditional acquisition process.

3.2 Essential Acquisition Activities

The essential activity of core asset acquisition, noted earlier, involves commissioning suppliers or contractors to

- develop a software architecture
- develop a production plan
- develop other core assets
- mine legacy assets to extract core assets
- manage, sustain, upgrade, and enhance the asset base *and* support product developers
- purchase or license commercial off-the-shelf (COTS) components

- a combination of the above

For product acquisition this involvement includes commissioning suppliers or contractors to

- develop a specific product *or* set of products from core assets according to the production plan

- maintain, upgrade, or enhance a product *or* set of products

- provide new assets (created during product development) for evaluation as candidate assets

Given these two essential product line activities of core asset acquisition and product acquisition, there are at least three derived product line acquisition activities that must be coordinated in the DoD acquisition environment. These activities include

1. acquiring an architecture and other elements of an asset base to enable a product line approach

2. acquiring software products that are developed using this asset base

3. acquiring the services to maintain and sustain the asset base while supporting the development and enhancement of derivative systems

Additionally, a comprehensive product line concept of operations to describe the coordination and interplay of these activities must be developed and maintained.

A product line acquisition program may be implemented at various levels—for example, system, subsystem, or component level. Traditionally, in following a systems engineering process, systems are decomposed into lower level systems, subsystems, and components. This is what DoD 5000.2R refers to as "component breakout." Another key step in the systems engineering process is the iterative allocation of system requirements to hardware and software. This allocation also occurs at the system, subsystem, and component level. A software product line approach may be employed at one or more of these levels, depending on many factors such as the application domain, degree of commonality and feature variability with other systems/susbsystems components, and availability of candidate (reusable) software assets.

To illustrate these engineering concepts, consider a fighter aircraft as an integrated system of subsystems and components that perform certain functions for the aircraft, such as navigation. A product line program could be established for a computational system used across a family of fighters or a product line program could be established for the navigation subsystems supplied to many airframes. This may seem to complicate the adoption of a product line approach for such systems. However, the key point is that each subsystem (being a member of its own product line) should have an acquisition program appropriate for that subsystem.

Using a product line implementation approach at the system, subsystem, or component level can yield significant benefits in terms of the time and cost required to field a product with proven capability and predictable quality attributes.

Two basic product line system *acquisition strategies* can be envisioned within the DoD environment: a "top down" strategy, and a "bottom up" strategy. (Certainly, a combination of these strategies can be used.) The top down approach acquires a set of core assets and then commissions the development of products (systems) from those assets. In the bottom up approach, a system is acquired during which the software architecture and (possibly) other components are acquired to be candidate core assets for a product line. Each strategy has advantages, disadvantages, and risks.
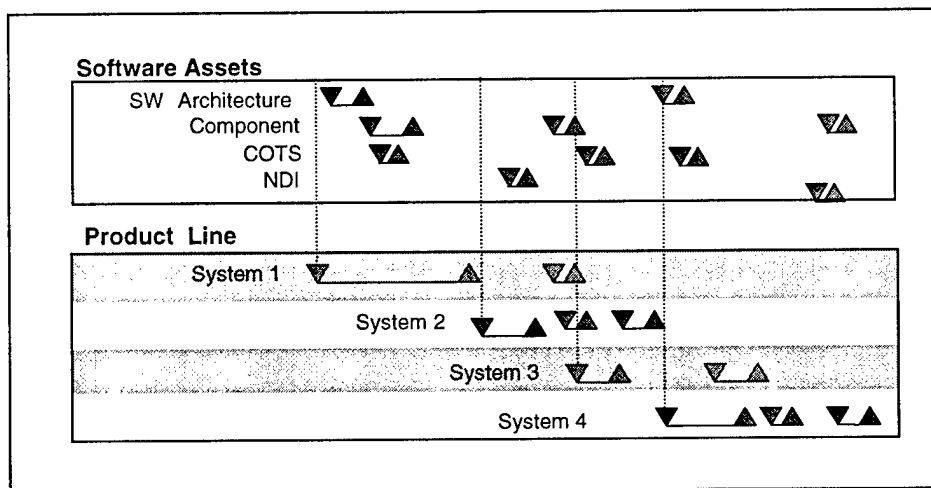
Figure 2: A Product Line Acquisition Program

From a life cycle perspective, the Gannt chart in Figure 2 (A Product Line Acquisition Program) illustrates what one possible product line acquisition program might conceptually look like. Here, core assets are acquired through the acquisition of system #1. Then each subsequent system in the product line is an integrated collection of these acquired components, COTS, and non-developmental items (NDI). These assets may be tracked and sustained separately from the systems subsequent to system #1, and are developed to meet the common and variable requirements of the entire product line.

Because asset redevelopment occurs less frequently than system development, these assets may be procured independently of a system. As an example, in Figure 2, the software architecture remains stable over the acquisition of the first 3 systems and their different versions. Perhaps due to changes in the technical architecture, the software architecture is revised in system #4. Common

components are upgraded as allocated functional requirements are added, such as with the acquisition of system #3. New COTS components are procured as they change in response to market competition.

From a "systems" point of view, a *software product line* may offer significant economies of scale at the appropriate system, susbsytem, or component level by providing the technical infrastructure and software asset base needed to exploit the benefits of systematic software reuse—even in the case where there may not be a standard platform (i.e., a common set of computer hardware resources). The classical output of the software product line is a complete *software system* consisting of a software architecture, common software applications, common software components, and a host of other reused assets (e.g., requirements, user scenarios, documentation, etc.). In a scaled down approach, the outputs of a software product line may be limited to producing common applications, or common components from which applications can be built.

The point is that the adoption of a software product line approach can have advantages at multiple levels. But choosing a product line approach will impact planning activities at the program, system, or subsystem procurement levels and will affect the content of acquisition packages and other procurement artifacts.

4   Summary and Conclusions

Software product lines have proven to be one of the most innovative and practical means to take advantage of reusable assets across projects. Data from industry clearly demonstrates that a product line approach can save money and result in faster time to market of higher quality systems. While there are also costs and risks for any product line program, if appropriately chosen and properly managed, the benefits of a product line approach far exceed the costs. By exploiting strategic software reuse, a well-managed product line approach holds great promise for the DoD in terms of efficiency, time to field mission capability, and quality.

The two essential activities in the software product line practice from an acquisition perspective involve the commissioning suppliers or contractors for core assets and commissioning suppliers or contractors for products constructed from these assets. This represents a new paradigm within the DoD environment and culture.

While it is evident that product line practice calls for a new technical approach, new non-technical and business practices are equally crucial. There is a constant need for strong visionary management to invest the resources in the development or acquisition of the core assets and to develop the cultural change to view new products in the context of a common set of core assets. This cultural change also manifests itself in requiring different acquisition approaches and different skills for the acquisition teams.

Other notes in this series will address some of the more significant business and acquisition challenges and issues for transitioning product line practice, such as: building a business case, measuring the impact of a product line approach, developing a product line acquisition strategy, choosing an appropriate funding model, and developing a product line concept of operations.

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Feedback and Contact

SEI Technical Notes on Acquisition Guidelines for Product Lines

Comments or suggestions about this first in a series of technical notes on *software product line business and acquisition guidelines* are welcome. We want this series to be responsive to the needs of DoD and government personnel involved in the business and acquisition aspects of implementing software product lines. To that end, comments concerning this technical note, inclusion of other topics, or any other issues or concerns will be of great value in continuing this series. Comments or suggestions should be sent to

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Industrial experience demonstrates clearly that a product line approach for software-intensive systems can save money and result in faster time to field higher quality systems. Many within the Department of Defense (DoD) recognize the benefits of product lines, but also recognize that there are significant challenges to adopting this approach. Many of these challenges stem from the fact that the DoD is in the business of acquiring systems rather than developing them.

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